EXPERIMENTAL STUDY ON COLLECTION EFFICIENCY OF SOLAR COOKING SYSTEM

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ABSTRACT. **The experiment conducted for the cooking the rice by using square parabolic solar collector. The heat transfer to the food is via heating oil. The main objective is to study the energy collection efficiency of solar cooker. From the experimentation it is found that the time required for cooking half kg of rice with 1 liter water is 3 hrs. The heat utilized for the cooking out of incident heat is 1.45%.**

Keywords: Solar Cooking, Energy-Exergy Analysis, Collector Efficiency

1. Introduction

Cooking is one of the daily activities for people. In most of the countries, rural people use wood, kerosene and other petroleum bi-products for cooking. It leads to deforestation and air pollution. Electric cookers and LPG are also used for cooking. The cost of electricity is high and LPG also burdened due to population. Therefore alternative non-conventional energy resources are required to overcome pollution, deforestation and increasing demand of fossil fuels. Solar energy can be used as alternate source of energy for cooking.

Several experiments were done for evaluate the thermal performance of different types of solar cookers by different researchers. The work of various authors is discussed below.

The efficiency of box type solar cooker using the standard procedure of cooking power is 26.7% (El-Sebaii et. al 2005). Performance of box type of solar cooker with two different cooking identical pots (with and without fins) is evaluated. The result shows that finned pot reduces time required for heating the water by 11%. And also rice was cooked in less time in finned pot (Rikoto I. I. et. al 2011).

Different types of solar cookers like box-type, panel-type and parabolic solar cooker are designed, constructed and investigated for the thermal performance. The result shows that the efficiency of box type solar cooker was greater than and less than the efficiency of parabolic type cooker and panel-type cooker respectively. But panel type of solar cooker attained the minimum temperature and parabolic type of solar cooker attained the maximum temperature (Akoy E. O. M. et. al 2015).

The efficiency factor of parabolic solar cooker under the no load and full load condition (i.e. cooker filled with different volume of water along with rice) is experimentally investigated. Experimental results show that the optical efficiency factor was very little affected by solar insolation (Gavisiddesha et. al).

Performance and testing of hot box solar cooker with heat storage materials is worked upon, so that cooking can be done at evening. The efficiency of the hot box storage solar cooker was found 27.5% (Nahar et. al 2003). Work is carried out on parabolic solar cooker with convective heat exchanger system for off-place cooking. Experimental result shows that, energy used for cooking out of incident energy was only 3.36% (Murti et. al 2007). Hybrid solar cooker with sensible heat storing material (oil), with this system cooking can be carried out during the day time and during evening period (Sonage B.K. et. al 2015).

The desired sensorial properties of food like flavor, color, texture depends up on the heat transfer to food. Therefore in most of food processing industry heat transfer media (oil) is used for heat transfer from source to the food (Fryer P. J. et. al 2004). Therefore present experimental investigation is carried on the performance of solar cooker with heat transfer media (oil), which is rarely seen in literature.

2. Methodology

2.1 Experimental Setup

The experimental set up is as shown in the Fig. 1. It consists of parabolic dish collector, copper tank, aluminium vessel, manual tracking mechanism, thermocouples and temperature indicating device etc.
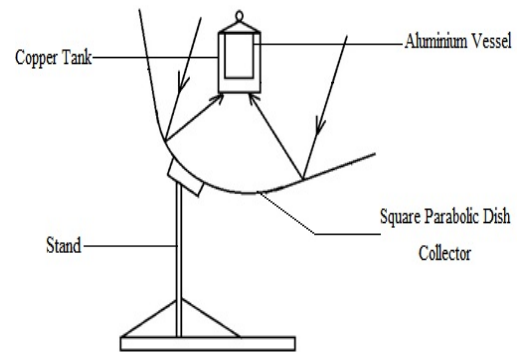

Fig. 1 Experimental setup solar cooker

Aluminium anodized parabolic dish collector having aperture area of 1.6 m2 with focal length of 400 mm is used as solar collector. The copper tank having diameter 0.22 m and height 0.23 m is used as thermal energy storage. It contains heating oil and it transfers the heat to the food. The aluminium vessel is main cooking vessel in which cooking is carried out. This vessel is inserted in to the copper tank in such way that it remain continuously in contact with heating fluid. Aluminium vessel has 0.20 m diameter and 0.10 m height. The simple nut and bolt arrangement is used as tracking mechanism. When the shadow of upper nut is exactly bottom of the nut then rays are perpendicular to face and all rays are concentrated at the bottom of the copper tank. Hence after 10 or 15 minutes, adjust the position of the collector to bring it in correct position.

The temperature measurement is very important because it is necessary to examine heating condition of various surfaces (side and bottom), food and heat transfer oil for analysis purpose. For this purpose K type thermocouples are used. Total eight thermocouples are installed in this setup for measuring the variation of temperature across the system. Out of these thermocouples five thermocouples are mounted on outer surface of Cu tank and one is at bottom surface of Al vessel as shown in Fig. 2. Remaining

two thermocouples are used for measuring the temperature of oil and food during the experimentation.
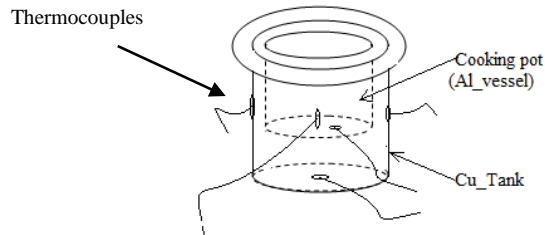

Fig. 2 Details of cooking pan and position of thermocouples

2.2 Testing Methodology

The experimental testing of the solar cooker was conducted at the host institute. The experiment was conducted in the month of January 2016 to evaluate the thermal efficiency of solar cooker. 4.5 kg heating fluid (soyabean oil) was filled in to the thermal storage tank. Cooking vessel was placed in to thermal storage tank in such way that the surface of the cooking vessel comes in contact with heating oil. All the elements of present system are assembled as shown in fig. 1 and provided with solar insolation.half kg rice with 1 liter of water was placed in to the cooking vessel. The experiment was started at 11:10 hrs. During testing, K-type thermocouples were used to measure the temperature at different point, such as the heating fluid temperature, surface temperature of thermal tank, cooking fluid temperature and ambient temperature. The mass of the food material was measured after food gets cooked.

3. **Performance of Solar Cooker**

Initial temperature of oil, food and ambient temperature were recorded as 31^0C, 29^0C and 32^0C respectively. The variation of solar insolation, ambient temperature, food temperature, oil temperature, surface temperature of copper tank and top surface temperature of aluminum vessel was noted at 15 minutes interval of time.

Thermal performance of system depends upon the input total incident energy, heat utilized for cooking, heat absorbed by the oil. Following methodology is used for data reduction.

Total input incident energy to absorber can be determined by (Ashok K. et. al 2009)

$$Q_{incident} = I_s \times A_{sc} \qquad (1)$$

And energy output i.e. energy utilized for the cooking is given by (Sonage, B. K. et. al 2015),

$$Q_{cooking} = \frac{M_f \times C_{pf} \times \Delta T_f}{\Delta t} \qquad (2)$$

Similarly un-utilized energy i.e. heat remains in to the heating oil was calculated by following equation

$$Q_{unutilised} = \frac{M_{oil} \times C_{poil} \times \Delta T_{oil}}{\Delta t} \qquad (3)$$

An energy efficiency of the solar cooker can be defined as the ratio of the energy gained by the solar cooker (energy utilized for the cooking) to incident energy (Sonage, B. K. et. al 2015)

$$\eta_{energy} = \frac{Q_{cooking}}{Q_{incident}} = \frac{\frac{M_f \times C_{pf} \times \Delta T_f}{\Delta t}}{I_s \times A_{sc}} \qquad (4)$$

Expression for the available energy flux, which is widely used, can be followed to calculate the exergy of solar radiation as the exergy input to the solar cooker (Petela 2003 and 2010)

$$E_{xi} = I_s \left[1 + \frac{1}{3}\left(\frac{T_a}{T_s}\right)^4 - \frac{4}{3}\left(\frac{T_a}{T_s}\right) \right] A_{sc} \quad (W)$$

(5)

Where, T_a is the ambient temperature (K). Although the surface temperature of the sun (T_s) can be varied on the earth surface due to the spectral distribution, the value of 5800 K has been considered for T_s. The exergy gained by the solar cooker (exergy output) is given by (Petela 2003 and 2010)

$$E_{xo} = \frac{M_f \times C_{pf}\left[\Delta T_f - T_a \ln\frac{T_{f,f}}{T_{f,i}}\right]}{\Delta t} \qquad (6)$$

An exergy efficiency of the solar cooker can be defined as the ratio of the exergy gained by the solar cooker (exergy output) to the exergy of the solar radiation (exergy input).

$$\eta_{exergy} = \frac{E_{xo}}{E_{xi}} = \frac{\frac{M_f \times C_{pr}\left[\Delta T_f - T_a \ln\frac{T_{f,f}}{T_{f,i}}\right]}{\Delta t}}{I_b\left[1+\frac{1}{3}\left(\frac{T_a}{T_s}\right)^4 - \frac{4}{3}\left(\frac{T_a}{T_s}\right)\right]A_{sc}} \qquad (7)$$

3.1 Calculation of heat losses

Heat losses from the absorber are by convection and radiation. Total heat losses from the absorber are the sum of heat losses from the sides of thermal tank and top of the vessel. Heat loss by convection and radiation was given by (Yahya, D. D., 2013)

$$Q_{conv} = Q_{conv,side} + Q_{conv,top}$$

$$Q_{conv} = (5.7 + 3.8 \times V)(A_{st} \times \Delta T_{st\_a} + A_t \times \Delta T_{t\_a}) \qquad (8)$$

$$Q_{rad.} = Q_{rad,side} + Q_{rad,top}$$

$$Q_{rad} = \sigma\left[\varepsilon_{Cu} \times A_{st} \times \left(T_{st}^4 - 9.28 \times 10^{-6}T_a^6\right) + \varepsilon_{Al} \times A_t \times \left(T_t^4 - 9.28 \times 10^{-6}T_a^6\right)\right] \qquad (9)$$

Therefore, total heat losses from absorber was

$$Q_{loss} = Q_{conv} + Q_{rad} \qquad (10)$$

The overall thermal efficiency is determined by following equation (El-Sebaii, A.A. et. al 2005 and Elamin,O. M. et. al 2015)

$$\eta_{overall} = \frac{M_f \times C_{pf} \times \Delta T_F}{I_s \times A_{sc} \times \Delta T} \qquad (11)$$

4. Result and Discussion

1. The square parabolic concentrator solar cooker was tested and the results are thus presented. The Fig. 3 shows that the variation in temperature of oil, food, average surface temperature of copper tank and aluminum plate with respective time. From the Fig. 3 it is found that maximum temperature of oil, bottom surface temperature of cooking pot and food temperature is 140^0C, 136^0C and 94^0C respectively at 14:10 hrs
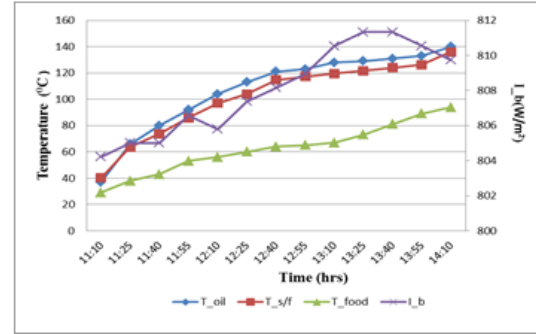
Fig. 3 variation of temperature and heat incident with time

2. Fig. 4 shows the variation of heat with respect to time. Heat losses found from the system are the convective and radiative heat losses, which are calculated by using equations (8), (9) and (10). The heat loss by convection depends upon coefficient of convection of air. The coefficient of convection is the function of velocity of air. During the experimentation average velocity of air was found to be 1.6 m/s. Hence the heat loss by the convection is more as compared to radiation, as of high temperature difference in surface of copper tank and ambient air. The Fig. 4 shows that the rate of heat stored in the oil is initially more but it decreases with time because the rate of heat stored in the oil depends upon the temperature difference i.e. change in temperature of oil. It is found that initially the heat stored in the oil is at a faster rate due to large temperature difference of the oil and bottom surface of copper tank but it decreases with increase in temperature of oil.
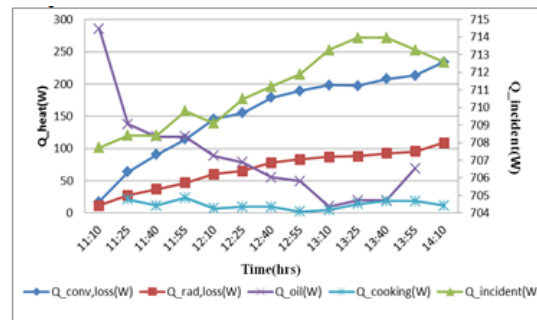
Fig. 4 variation of heat with respective time

3. The heat transfer to the food from the solar concentrator is through the bottom surface of copper tank, oil and aluminum vessel. It means that there are convective and conductive thermal resistances of oil, Al and Cu metal respectively. Hence the change in temperature of food is very slow. From equation (2) and equation (6), it is clear that the efficiency of energy and exergy depends upon the change in temperature of the food. Hence Fig. 5 shows that the energy efficiency is high and it decreases with respect to time, but exergy is initially low and it increases with respective time.
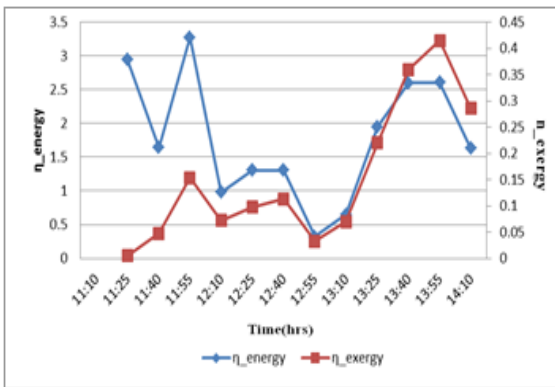

Fig. 5 Variation of efficiency with time

4. The thermal conductivity of thermic fluid seems to decrease with increase in temperature of the fluid and heat transfer coefficient increases with respect to temperature.

5. We have thermal diffusivity $\alpha = k/\rho.C_p = 4.399$ m^2/sec. The thermal diffusivity of thermic fluid decreases with increase in temperature difference of oil and hence the cooking time increases.

6. In convectional solar cooking system the rate of cooking is affected due to intensity of solar radiation but by using the thermic fluid, even though there is fluctuation in intensity of solar radiation the rate of cooking is stable due to the storage of heat into the oil during the higher intensity period. Thus uniform cooking is obtained.

7. $$Q = M_{oil}C_{poil}\Delta T_{oil} = 505KJ$$

About 505 KJ of heat remains un-utilized by the use of thermic fluid which can not be furthermore used to cook the food at 94^{0}C or more. So the use of thermic fluid for indirect heating of food is disadvantageous for just to get uniform cooking. Uniform cooking or over heating may be avoided by agitation.

5. Conclusion

From the experimentation it is found that the time required for cooking half kg of rice with 1 liter water is 3 hrs. The heat is transferred to the cooking rice by natural convection through the oil. The overall thermal efficiency of system is determined by using equation (11); it is found to be only 1.459%. Heat stored in the oil i.e. unutilized heat for the cooking, heat loss by convection and radiation are determined and they were found to be 43.254%, 37.921% and 15 % respectively.

References

Ashok, k. & Sudhir, C.V.(2009) Proposal for new world standard for testing solar cookers. Journal of engineering science and technology, vol. 4, no. 3, 272 – 281.

Dasin,D. Y, Habou, D. & Rikoto, I.I., (2011) Performance evaluation of parabolic solar concentrator against international standard procedure in the tropical Environment. Nigerian Journal of Renewable Energy, 15, 20-28.

Elamin,O. M., Akoy, Abdalla, I. A. & Ahmed (2015) Design, Construction and Performance Evaluation of Solar Cookers. Journal of Agricultural Science and Engineering, Vol. 1, No. 2, pp. 75-82.

El-Sebaii, A. A. & Ibrahim, A. (2005) Experimental testing of a box solar cooker using the standard procedure of cooking power. Renewable energy. 30: 1861-1871.

Fryer, P. J. &Robbins, P. T. (2004) Heat transfer in food processing: ensuring product quality and safety. Applied Thermal Engineering, 25 (2005) 2499–2510.

Gavisiddesha , Revankar , P. P. & Gorawar M. B., Evaluation of Thermal Performance of Paraboloid Concentrator Solar Cooker. International Journal Of Innovative Research In Technology & Science, Volume 1, Number 3.

Murty, V.V. & Gupta, A. (2007) Evaluation of thermal performance of heat exchanger unit for parabolic solar cooker for off place cooking. Indian journal of pure and applied physics, Vol. 45, pp. 745-748.

Nahar N. (2003) Performance and testing of hot box storage solar cooker. Energy Conservation and Management, 44, 1323-1331.

Petela, R. (2003) Exergy of undiluted thermal radiation. Solar Energy, 74, 469-488.

Petela, R. (2010) Engineering Thermodynamics of Thermal Radiation for Solar Power Utilization. McGraw-Hill, New York.

Sonage, B. K. & Gavali S.(2015) Analysis of parabolic concentrator type solar cooker by using heat storing materials. Dissertation report.

Yahya, D. D.(2013) Experimental investigations of heat losses from a parabolic concentrator solar cooker. African Journal of Engineering Research, Vol. 1(3), pp. 90-96.

Nomenclature

$Q_{incident}$	Total input incident energy to absorber	W
$Q_{unutilised}$	Un-utilized energy or heat stored in to the oil	W
$Q_{cooking}$	Heat utilized for cooking	W
$Q_{conv.}$	Heat losses from the absorber by convection	W
Q_{rad}	Heat losses from the absorber by radiation	W
Q_{loss}	Total heat losses from the absorber	W
η_{energy}	Energy efficiency	%
η_{exergy}	Exergy efficiency	%
E_{xi}	Exergy input	W
E_{xo}	Exergy output	W
T	Time required for cooking	min.
I_b	Solar insolation	W/m^2
I_s	Insolation falling on cooker aperture	W/m^2
T_s	Solar temperature	K
$\dfrac{T_{f,f}}{T_{f,i}}$	Ratio of food temperature	-
T_{st}	Surface temperature of thermal tank	^{0}C
T_t	Surface temperature top Al plate	^{0}C
T_a	Ambient temperature	^{0}C
A_{sc}	Aperture area of collector	1.6 m^2

A_{st}	Side surface area of thermal tank	0.16 m^2
A_t	Top surface area of Al plate	0.038m^2
ε_{cs}	Emissivity of collector dish material	0.55
ε_{Cu}	Emissivity of material of thermal tank	0.570
ε_{Al}	Emissivity of material of top surface	0.090
ΔT_f	Change in food temperature	^{0}C
ΔT	Total time required to cooking food	sec
ΔT_{oil}	Change in oil temperature	^{0}C
Δt	Time interval	sec
ΔT_{st_a}	Difference in temperature between hot tank and ambient	^{0}C
ΔT_{t_a}	Difference in temperature between top surface and ambient	^{0}C
C_{poil}	Specific heat capacity of oil	1.97 KJ/Kg.K
C_{pf}	Specific heat capacity of food	1.3925 KJ/Kg.K
M_f	Mass of cooked food	0.5 Kg
M_{oil}	Mass of oil	4.5 Kg
V	Average Velocity of air	1.6 m/s^2
σ	Constant	5.67×10^{-8} W/m^2 K^4